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ABSTRACT

Because interaction is the only observable information people have about teaching processes, it follows that the primary aspect of intelligent tutoring systems (ITS) is interaction, and that future work on domains or student models should be driven by the needs identified in the study of interaction. This paper begins by examining the idea of teaching styles in terms of the implications that they have for types of interaction between student and machine. The second and third sections describe the teaching knowledge of two existing ITS systems, IMPART and Dominie, which are models of interaction. It is noted that the interaction in IMPART is based on cognitive models of dialogue in humans, while the interaction in Dominie is based on cognitive models of thinking. Subsequent sections relate these systems to current studies of dialogue, and a set of components is proposed that must exist in a tutoring system if it is to support the kinds of interaction described. It is concluded that the proposed model requires approaching interaction as a planning process in which multiple plans are created simultaneously at a variety of levels of abstraction and completeness. (27 references) (DB)

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Dialogue and teaching styles

1. Introduction

This paper discusses the role of knowledge about interaction in Intelligent Tutoring Systems. In particular, it examines the idea of a "style of teaching", and discusses the implications which teaching styles have for the form of interaction between student and machine. The first section discusses the reasons for studying teaching styles, the second and third describe the teaching knowledge of two existing systems which embody models of interaction. Subsequent sections relate this to work on dialogue and propose a set of components which must exist in a tutoring system if it is to support the kinds of interaction described here.

2. What are we trying to do?

There can be a variety of reasons for studying Intelligent Tutoring Systems. The most obvious is to attempt to build a device which satisfies an educational need. In this case, we do not mind whether our system is human-like or not, provided that it is an effective educational tool. This is similar to the more general position taken in "hard" Artificial Intelligence which suggests that, provided a program exhibits "intelligent behaviour", the mechanisms by which this is achieved are of no concern. This is not such a clear-cut position in the case of Intelligent Tutoring Systems, because our systems necessarily interact with human beings, so they must, at some level, have human-like properties. This is particularly true in the field of student modelling. It is not clear that a psychologically implausible student model can be constructed. Although it seems clear that we must examine human teaching, since humans are the only examples of teaching systems which are available for study, this does not imply that our tutoring systems should be constrained to human-like interaction. While taking human interaction as the base of study, we must continually consider the "space of possible educational interactions" which may involve forms that cannot be executed by a human teacher.

A second reason for studying Intelligent Tutoring Systems (or, more generally, AI and Education) may be the desire to understand better what is meant by education, and to help expand educational theory in such a way that human teachers can improve their educational interactions. This can be done independently of whether we use the knowledge acquired to implement human-like computer based teachers. What is the contribution that AI makes to education theory? A number of researchers (e.g. [Peters 1966] [Bruner 1966]) have divided an educational theory into two components. The first is an educational philosophy which provides the goals and values to be espoused by a particular educational theory. The

second is an educational psychology which, given the goals and values, explains what we should do in order to achieve those aims, and provides a model which should explain why doing those things is effective. It is in this latter part of an educational theory that AI can serve a purpose.

Psychology (especially Cognitive Psychology) has been strongly influenced by the use of the computational metaphor. Before this was available, it was difficult to express theories about information processing systems in a precise enough form to enable detailed comparisons. Attempts at mathematical models of psychological theories were of limited success. The advent of the computer in general, and AI in particular, provided a language within which information processing systems could be discussed. Information processing and its implications for the architecture of the human processing system could be discussed using the language of computing. More than this, a computer program permits us to build a precise formal model to represent a theory. This model is executable, is (in some sense) complete, and provides concrete form for the predictions of the model. Combining the information processing ideas with more traditional Cognitive Psychology has led to the new field of Cognitive science. This field has changed the way we think about the mind.

From the perspective of education theory, we can expect the computer to have a similar impact for similar reasons. The study of the psychological component of the theory is amenable to the same computationally based techniques which have changed the way that psychological theories are represented. AI can provide tools to express educational theories in a more precise form, to decide criteria for testing those theories, and to compare the predictions of the theories. Since the Education theories which we are discussing involve explaining appropriate educational processes and the way in which these processes operate, we expect the theories to incorporate models of teaching and learning, as well as more general claims about the architecture of the mind and the implications that this has for Education. Given an educational theory on this scale, which is embodied in an AI based approach, one outcome that we would expect is a runnable, predictive model of educational processes that can teach in a similar way to a human teacher.

This implies that we must engage in Cognitive Science, whatever the ultimate goal of our tutoring system. We need to know how individuals acquire, represent and use knowledge. We must seek to understand the mechanisms by which this process can be facilitated. The work reported in this paper is intended to approach one particular question. What do we mean by teaching? It is based upon the assumption that teaching is a specific case of more general strategies of interaction between humans.

Tutoring systems often focus on issues of student modelling or domain representation. Why should such an emphasis be placed on interaction

here? The reason is that the interaction is the only observable information we have about teaching processes. Building student or domain models which are sophisticated but cannot be effectively used to their full potential in the interaction is a pointless exercise, since there is an infinite set of such models. The claim being made here, and expanded upon in [Elsom-Cook in press] is that we should explore interaction as the primary aspect of tutoring systems, and that work on domains or student models should be driven by the needs identified in the study of interaction.

3. IMPART: An educational dialogue mechanism

IMPART [Elsom-Cook 1984] is a tutoring system for Lisp constructed around the discovery learning paradigm. It embodies a model of interaction based upon cognitive models of dialogue in humans. In particular, it attempts to combine focus-based and functional approaches.

A focus-based approach to dialogue (e.g. [Grosz 1977],[Reichmann 1978]) attempts to describe the way in which topics move over the course of an interaction. It is based around the use of "context spaces" associated with particular topics. These focus spaces can be "open", "closed" or "active". An active context space is one in which the topic is currently the topic being discussed in the dialogue. An open context space is one in which the topic has been active but is no longer so. An open space can be reopened. A closed context space describes a topic which is considered completed. For it to be discussed again it must be reintroduced as though it was a new topic.

To illustrate this consider a conversation about whether or not to go and see a film. Suppose the participants begin discussing the merits of the particular film in order to make their decision. At this point, the active context space is the merits of the film, while the context space containing the decision about whether to go to it is open. That is, it is not what is currently being discussed, but it can be returned to. If a decision is made to go to the film, and the conversation passes on to discuss where to eat beforehand, then the previous two spaces will be closed.

Work on focus-based approaches has concentrated on analysing dialogues, and has attempted to find rules marking topic changes. These rules are essentially descriptive, however.

Function-based approaches (e.g. [Levin 1978],[Power 1979]) model the function of segments of dialogue in a way which is independent of content. It has its foundations in work on adjacency pairs [Schegloff 1973], and led to the definition of "dialogue games". Dialogue games are segments of dialogue designed to achieve a particular goal. They can be embedded within one another to produce larger structures of interaction.

IMPART combines these approaches in a demon-like mechanism similar to the issue recognisers in WEST [Burton 1982]. Each topic in the system is represented by an active demon called a "topic controller" which has a number of procedural and declarative attachments. These controllers repeatedly make bids for control of the interaction, and a "conversation controller" resolves and combines the bids to produce segments of dialogue. The topic controllers use dialogue games to communicate with the user, and the conversation controller can constrain the game choices to improve the coherency of the interaction. For the purposes of this paper, the conversation controller is the most interesting component. Let us examine a plan for a segment of conversation and see how it is generated.

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(evaluation impart (function impart (argument illustrate
action-probe) (value illustrate)))
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In this instance, the topic controllers "evaluation", "function", "value" and "argument" are communicating with the student. They have been constrained to use a mixture of three games: "impart" (give information), "illustrate" (show a concrete example) and "action-probe" (ask the student to do something). The order and activities of the topic controllers are constrained using a set of heuristics. Some of these are given below:

- Introduce the topic which made the highest "importance" bid first
- If a topic and a subtopic made high bids, introduce the major topic but constrain it to introduce the subtopic in context
- If more than one topic uses the same subtopic, introduce the subtopic then the major topics
- Do not use the same dialogue game more than twice in a segment
- Illustrate a topic before imparting information about it

IMPART used twenty such rules, but these give a reasonable flavour.

3.1 Strengths and weaknesses

The primary strength of IMPART lies in the attempt to combine existing models of dialogue processes to generate a structured interaction. It has some longer-term "plan" of interaction which goes beyond the purely reactive (or single utterance) nature of many systems.

There are many weaknesses to IMPART. It is, in essence, an "engineering" approach to educational interaction. This is particularly noticeable in the heuristics for control given above. These rules do not even have the claim of being empirically derived in the way that those of Collins [Collins 1980] were. IMPART succeeded in separating out knowledge of the interaction in a way that made it possible to change it

independent of the rest of the system, but it made no contribution to formalising "educational" knowledge about interaction.

4. Dominie: multiple styles and a strategy

DOMINIE [Elsom-Cook 1987] is a tutoring system which embodies a number of distinct teaching styles and an overall strategy. A major goal behind the system was to try and represent a number of different teaching strategies explicitly. The criteria for success do not require the styles to be educationally or psychologically valid. At this stage of development it is sufficient that the strategies be distinguishable and (if possible) recognisable. By distinguishable I mean that the styles should produce different behaviours from each other. For a strategy to be recognisable, it should have some observable features in common with the paper description of the characteristics of that style.

DOMINIE teaches a student to use a computer application. It can teach any application which can reasonably be regarded as a procedural task in which a major goal can be repeatedly divided into subgoals which can be achieved by carrying out some actions upon the computer. An individual task is represented as a plan composed of these goals and subgoals. Examples of appropriate tasks include the customisation of office automation systems, the maintenance of electronic telephone exchanges and maintenance of system accounts on a mainframe. It is less appropriate for tasks such as learning to use a database package, since the procedural decomposition model is not necessarily appropriate in these cases.

The system embodies eight teaching styles, and chooses between them during the course of interaction with a particular student. We will only discuss three of the styles here. The third will be discussed in detail to give a feel for the extent to which "educational knowledge" has been formalised in the system. Following this we will proceed to a brief discussion of the strategy for selecting between styles.

4.1 Cognitive apprenticeship

There has been a lot of interest recently in a teaching technique known as 'cognitive apprenticeship' [Collins 1987]. This is based on the idea that cognitive skills can be learnt in the way that crafts were learnt from an expert in that craft. The apprentice commences by watching the expert in action and asking questions. As time passes the expert allows the apprentice to perform small parts of the whole task. These parts will gradually increase in size until the pupil is able to perform the whole of the task in question. The claim for cognitive apprenticeship is that this technique operates beyond the level of manual skill acquisition. Problem-solving, reasoning and other cognitive processes are claimed to be amenable to this approach. This approach relies on the expert having

reasoning techniques which are meaningful to the pupil. In the case of a computer based tutor, the computer must reason using glass-box (psychologically valid) techniques if it is to attempt to teach in this style.

As far as DOMINIE is concerned, it is a working assumption that the 'reasoning' which it uses (i.e. the goal structures generated by the planner) are meaningful to the users. Since these structures are input by experienced human users this is a reasonable assumption, but one which is to be investigated in field trials.

The tutor must select an appropriate part of the domain and teach it to the student using a mixture of demonstrations and exercises for the user. In selecting an area to teach, our assumption is that the area should be slightly beyond the current state of knowledge of the pupil (as inferred from the student model). There should be enough material to give the exercise a structure and purpose, but not so much that the pupil is overwhelmed. In terms of our plan tree this is represented by choosing to teach a goal within the tree for which all sub-sub-goals (if they exist) are already known to the pupil, but the majority of the sub-goals are not. Dominie would actually teach such a goal by demonstrating it (which includes a demonstration of the subgoals). The tutor then explicitly breaks the goal into subgoals, and for each subgoal demonstrates it and then asks the pupil to carry out the same subgoal. If any of the subgoals are already known to the user, the tutor simply asks for them to be carried out (rather than demonstrating them). Finally the tutor demonstrates the overall goal again and asks the pupil to perform the whole task. At any point during this process the pupil can ask for an explanation in terms of the role of this action within the overall plan, or the domain concepts with which this plan is associated.

4.2 Successive refinement

Successive refinement is a top-down approach to teaching. It derives from the work of A.N.Whitehead [Whitehead 1932]. The basic principle is that a good teacher should be able to explain a topic at a number of levels of detail, always providing an interaction at a level which is meaningful to the pupil in her current state of knowledge. In particular, a domain which contains an overwhelming number of details should be taught initially at a very general level, telling a coherent story but omitting the full ramifications of the topic. This provides the pupil with an overview and a systematic framework into which subsequent teaching of the domain can be fitted. As the pupil becomes more sophisticated, a more powerful model of the domain may be taught. This is likely to involve explicitly highlighting erroneous simplifications which the tutor made for pedagogical purposes and actively supporting the construction of new, restructured models of the domain.

It has recently been pointed out [Collins personal communication] that there are three well defined methods mixed together here. One is the restructuring approach based on offering simple models which make incorrect predictions, and are subsequently replaced with models that are better but involve a different view of the domain. A second is to offer the student a model which can make general predictions in restricted parts of the domain and can be refined by extending it without changing the basic conceptualization (this is the approach taken by White and Fredrikson [White 1988] for example). A third is the "framework" approach - providing the student with a comprehensive, general, but very weak overview of the domain into which details can be slotted. This latter is really a motivational approach, attempting to get the student to learn details by knowing where they are going. It is this third method that was intended in this implementation.

DOMINIE selects the highest level untaught goal in the plan. It then uses information about the concepts associated with each goal in that tree to generate 'weighted subnets' of the declarative knowledge in the system. These nets identify relevant concepts and assign them an importance in terms of the current plan. This process is described in more detail in [Spensley 1987].

Starting from the highest procedural goal, the tutor presents the major concepts associated with that goal and briefly summarizes the subgoals and actions which are involved in achieving the goal. On subsequent passes the subgoals are presented in a similar fashion. This process is repeated recursively through the plan tree. The level of explanation given at each point depends on the importance of the concepts within the weighted subnets and the level of understanding of the concepts and procedures which the pupil already has.

4.3 Discovery learning

The nature of discovery learning remains a subject for debate. Some educationalists see such learning as implying a completely free activity on the part of the pupil. At the other extreme the pupil may have the impression of discovering new material for herself, but the task is actually carefully structured by a teacher who knows in advance the sequence of discovery which the pupil will make. In our model of this style, a teacher is necessary to set up an appropriate environment in which the learning can take place, and to provide guidance to the pupil when requested or when the pupil is in difficulty. A major part of the teacher's action is to assess the current state of knowledge of the pupil, and to select a task for the pupil to explore which is slightly beyond the current state of her knowledge, but not so much so as to be too difficult for her to achieve. Choosing such a task can be extremely complex and may involve finding similar situations in which the learner has made an appropriate cognitive leap, or identifying knowledge which the learner can bring to bear on the

task. In our case we only attempt to model the selection of one type of area appropriate to discovery learning: that is, an area which is new to the student but which has a structure analogical to something which the student has already learnt.

Having chosen an area, the tutor should monitor the student working in that area. If the student gets into difficulty or asks for help then the tutor should provide it. In general this help could take any of a number of forms. Since we are restricting ourselves to analogical reasoning the help can be similarly restricted. The tutor offers guidance by a sequence of progressively more detailed hints which give information about the analogy with previous knowledge. In terms of our knowledge representation this is fairly simple. An appropriate area for discovery learning by analogy is one in which the student knows most of the skills involved in a task, but does not know some part which is analogical to something previously learnt. In our usage two goals are analogous if they involve the same procedure in different problem contexts with different parameters. The first level of hint which the tutor offers is identifying the context in which the analogous procedure arose. Subsequent hints identify individual parameters in the two contexts.

Let us now examine the actual rules within Dominie which embody this particular strategy:

- 1) In order to find an appropriate area to teach, search the plan tree for the current task in a top-down, breadth-first manner, search at a given ply being from left to right
- 2) A segment of the plan is appropriate if it is untaught and it is analogous to a goal which is already known
 - 2a) Two goals are considered analogous if they are represented by different parameterizations of the same planning procedure
- 3) Present the problem to the student then do "discovery assessment"
- 4) To present the problem to the student, present an introduction to the strategy and then offer the problem context
 - 4a) Presenting a strategy involves displaying motivating text and an explanation of what the student should do. If it is the first time the student has used the strategy present a detailed explanation, otherwise present a short summary
 - 4b) Presenting a context involves presenting the goal of the problem and the reason that goal is relevant to the overall task
- 5) To carry out discovery assessment ask the student to demonstrate the procedure and monitor the student performance
- 6) At any time while monitoring performance the student can ask for a hint or a demonstration of the correct next step
- 7) If the student asks for a demonstration, only give one if all the hints have been used

8) If the user asks for a hint then...

- 8a) If the user tried an action associated with a procedure but omitted an action associated with the preconditions of the procedure then remind the user what the procedure is and state the omitted precondition
- 8b) If the user is in one branch of a disjunct and has executed an action from the other branch, then tell the user the critical post-test which should determine the branch to choose
- 8c) Otherwise, if this is the first time the user has asked for a hint then identify the context of the analogy
- 8d) Otherwise identify a parameter of the procedure and give its old value

9) Monitor student performance by generating a solution to the problem from the planner and seeing if it matches the student actions

- 9a) If the match is complete, increase confidences in the student model and present the student with a summary of what she did
- 9b) If the student moves away from the correct solution, decrease confidence in the student model and offer the hint menu

The rules divide into two sections: rules 1 and 2 are concerned with what to teach, while rules 3-9 are concerned with how to teach by this method. This division of decisions occurs in all the styles. Choosing what to teach has two components: the first (rule 1) tells us how to look for something to teach, while the second (rule 2) tells us how to identify an appropriate area when we find it. Again, this division is common across all styles. The remainder of the rules are fairly self-explanatory and differ for each style. We have found no common patterns here. The sort of differences embodied can be seen by comparing "monitoring" as defined in the above case with "monitoring" in the "practice" strategy. In discovery learning, monitoring involves updating the student model and only offering advice if the student requests it, no matter how far the student deviates from the correct course of action. In the "practice" case, monitoring is conducted by a mechanism akin to Anderson's "model-tracing" [Anderson 1982] in which any deviation from the correct solution is immediately remediated.

4.4. Strategy selection

Given the eight strategies embodied in the system, the tutor must decide which is most appropriate at a given point. The primary decision which the tutor takes when it considers a strategy change is the balance of teaching and assessment in its activity. Obviously the tutor wants to present new material to the student, but it also has goals of ensuring that the student has understood the material and checking that its model of the student is still accurate. The system therefore starts by teaching when it has a new pupil. This is based on the assumption that the pupil knows

nothing about the area which is being taught. As the interaction progresses the gap between material taught and material assessed widens. When this factor has become sufficiently large the tutor will switch to a strategy which increases the amount of assessment.

Within this decision about teaching or assessment is a decision about the general area on which the tutor will focus. The two are linked together and result in a compound decision which encompasses teaching new material, reteaching old material and assessing or reassessing the student's understanding. The system then has a set of heuristics to give an "order of preference" to the possible styles. These rules are intended to embody a strategy of choosing the least interventionist method which is applicable.

Once these decisions have been made the system uses local rules (like those given above) to find an appropriate subarea to teach, using the preferred style. It is possible that no appropriate area can be found within this topic. In that case, the style is obviously inapplicable in this situation and the tutor will try and use the next preferred style on the list.

4.5 Strengths and weaknesses

Dominie succeeded in capturing eight different teaching styles at a level of detail which allowed them to be distinguished, and where an observer can see the relationship of a given style to the paper description. It also provided a mechanism which switches between these styles in a reasonable manner. The whole system has been successfully field-tested in several countries. Is this therefore the answer? Do we simply need to refine the rules representing the styles and incorporate more rules for other styles? The answer is (of course) no.

The rules given produce a reasonable behaviour, but there are several reasons why they are inadequate. We will consider the question of strategy. It is apparent that human teachers do not switch between styles in the extreme manner of Dominie. Rather, they pursue one style, even when it is failing, and try to repair the failures. Is this simply because teachers can only remember one thing at a time? What we have omitted entirely from the discussion is any consideration of WHY the rules achieve something, and until we do this of course, we cannot consider their relationship to the learner. To have a strategy which reasons about the styles, the styles must be captured as something more than simply descriptions of behaviour. We need a model that explains those styles and, preferably, a model from which those styles and their variants can be derived. The use of rules has been helpful in marking out the range of things to be studied when examining teaching knowledge, and in showing what can be done, but to really capture appropriate interaction processes we must go beyond this and discuss goals, intentions, reasoning processes

and deeper models of interaction. The purpose of the next section is to raise and discuss some of these issues.

5. Implications of teaching style for dialogue mechanisms

5.1 Dialogue models and teaching plans

Some approaches to modelling dialogue were discussed above. These models have now effectively been superseded by combined theories of focus and function (e.g. [Grosz 1986]) and by models of speech acts as derived from deeper goals (e.g. [Cohen 1987],[Appelt 1982]). The dialogue games approach gave one level of analysis of a dialogue, but ultimately it was a descriptive tool. It did not explain where the goals for the games came from, nor how they mapped into specific sequences of utterances. Both were simply accepted as "conventional". More recent systems have become much more formal, commonly using S5 logics and possible world semantics (e.g. [Appelt 1982]). The overall view is that a dialogue model must take as its starting point the goals, intentions, desires, wants etc of the participants (see Beveridge and Rymaszewski; this volume). Current models assume that the generation process is one of moving from a goal to an utterance by generating a plan in terms of intentional structure. This plan is generated by reasoning about the way the world should be once the goal is achieved, and trying to ensure that an utterance constrains there to be such truth in all possible worlds. A major advantage of this approach is that it does offer us explanatory power at all levels, although to explain low-level detail such as the exact form of an utterance our planner must have stronger ideas than currently exist about the interaction of multiple goals.

The recognition process in dialogue is seen as the reverse of the generation process described here. A speaker receives an utterance, and must try from this to infer the plan, and hence the goal, which the speaker must have had. How the speaker deals with this goal once recognised passes into the realms of theories of agenthood. These are discussed in the next section.

5.2 Theories of agents

In earlier discussions we have emphasised the need for our tutor to reason explicitly about its actions, and to take into consideration the state of the pupil. Both of these issues are approached in work on theories of agents. The goal of this field of research is to try and define what it is that makes an information processing system an "agent" as opposed to being a reactive system which simply does what it is told. Agents are regarded as entities which are capable of taking actions rationally and autonomously in some world. We will examine one theory, which goes beyond this viewpoint and attempts to discuss agents as social, interacting entities.

This is clearly the situation which we are trying to achieve with a tutoring system.

Kiss (1988) centres his theory of agents on the idea that an agent must possess attitudinal states. He then posits that agents are "...capable of taking many different kinds of attitudes to the world, and through the manipulation and utilization of these attitudes are capable of pursuing their interests". Kiss is concerned with the underlying nature of consciousness, and the architecture of intelligent systems. For the purposes of this paper we will review some of the major points which he makes without detailed exposition or justification.

In discussing computer agents interacting with users, Kiss modifies the idea of autonomy to deal with the restricted class of agents which are autonomous subject to constraints imposed by the interests of the user. This is precisely the class of systems which we require for an ITS. Kiss identifies processes of conflict and cooperation as key aspects of these agents, and proposes a mechanism based upon deciding commitments to actions (or goals or other attitudinal states).

In the current version of the theory, three classes of attitude are identified: cognitive, conative and affective. The cognitive attitudes are knowledge and belief (the distinction being that knowledge is definitely true in the world, whereas beliefs are held to be true by a given agent). The primary conative attitudes are wants and intentions. A want is an attitude towards some proposition or state. An intention is an attitude towards an action, specifying a (possibly conditional) commitment by the agent to carry out that action. Affective attitudes express values of other attitudes or states in terms of liking or disliking.

The agent is viewed as a system which is continuously evaluating potential actions with respect to its system of values, making commitments to action, and carrying out those actions. Actions can be of three types: deliberative, basic and reflex. Reflex actions are immediate responses to situations, deliberative actions are parts of the reasoning process, and basic actions are things which may result from that process, but have no substructure. These actions do not necessarily occur in the world. For example, deciding to take a decision is an action.

The evaluative mechanism must be able to select between attitudes and states. This is achieved by positing a value system within each agent. The theory specifies the way in which states can acquire a value through their hedonistic attributes. These values, in combination with cost assessments (the amount of work required to achieve a state) allow us to create a value for the 'want' associated with that state. The values of a particular sort of attitude form a partially ordered set. If one item has a

higher value than another in this set, then the agent is said to have a 'preference' for the first over the second.

This model provides us with a framework in which to express the reasoning and decision-making processes of a tutor. In interacting with a student, the tutoring system will extend its own attitudinal system with attitudes about the students system and values. There is no implication that the attitude system of the agent must be exact, nor that it must be consistent.

By thinking of our tutor in terms of this model of agents, we gain several advantages. One advantage is that we can talk about intentions and wants in a manner that allows us to provide more detailed models of the reasoning involved in a decision by the tutor. The terms that we use, and their relationships, can be justified in terms of a deeper model of the architecture of agents, but we can worry about how these components are used together rather than seeking to explain the underlying theory. A third advantage is that the agent theory provides a very general model of action, which we can use to integrate the features of the planning approaches and the situated action approaches into a single uniform framework.

5.3 Situated action and opportunistic tutoring

Some recent work on human-computer interaction [Suchman 1987] has questioned the role of planning in cognitive science in general, and models of interaction in particular. Suchman presents a caricature of AI planning work, shows how this sort of planning is inappropriate for interaction models, and offers the alternative of "situated action". Unfortunately, this is also a caricature of an extreme position. The mechanisms of interaction must actually lie between these two extreme positions. Nevertheless she makes a number of important points which must be taken into account.

Suchman offers the following definitions of the two extremes

"On the planning view, plans are prerequisite to and prescribe action, at every level of detail. ... The alternative view...is that while the course of action can always be projected or reconstructed in terms of prior intentions and typical situations, the prescriptive significance of intentions for situated action is inherently vague." [Suchman 1987]

The essential contrast that she expresses is between action which is completely planned in detail in advance of execution, and actions which occur in response to a concrete context. She points out that, in general, plans like this cannot be generated prescriptively, and that they can be an

artifact imposed in a post-hoc manner by the observer of an interaction. She points out that we cannot anticipate all eventualities, and therefore cannot plan for them. In terms of situated action, the action (or utterance) derives its significance from the context in which it occurs, without necessarily being used to identify the pre-existing plan of the agent performing the action. She is deliberately vague about the nature of this context, suggesting it includes purposes and possibly an agenda. This vagueness is not a limitation of the approach, she claims, but an inherent part of the nature of interaction. She claims of her approach that

"...it recommends that we turn our focus from explaining away uncertainty in the interpretation of action to identifying the resources by which the inevitable uncertainty is managed"

In justification of this she hints at the frame problem in interaction, but, more importantly, talks about the inexactness of our inferences about intention. We cannot, in general, infer another agent's intentions exactly and, more importantly, we do not need to. An intention is only inferred to the level of detail necessary for action. If, for example, an agent has a strong goal of pleasing another agent, then the first agent only needs to satisfy him/her self that a request from the second agent is not impossible and will not harm the first agent. No more detailed analysis of intention is necessary. Suchman also points out that much of dialogue is repair (or elaboration), in which an utterance which failed to express an intention adequately to result in action is refined by collaborative problem-solving between the two individuals.

In Suchman's case study of interaction (with an expert help system) there is unfortunately an additional confusion which makes the implications for interaction less clear. In most of the book, she has been discussing plans for dialogue. In the case study the plan to which she refers is the plan for achieving the task. These two plans are somewhat different. The task plan corresponds to the dialogue plan in cases such as that of Grosz work [Grosz 1977], where a single expert who knows "the right way" to perform the task is interacting with a novice. In Suchman's case there are two novices, and considerable ambiguity in the way in which the help system expresses the plan. (It is interesting to compare this with Dominie, which uses essentially the same representation of the domain). One further point which Suchman makes is that the computer and humans in this case cannot have a shared context, because not all the things which are accessible to the human are accessible to the computer. In conclusion, Suchman points out three major issues arising from this asymmetry between human and machine: 1) How can we extend machine access to actions and contexts 2) How can we make the machine's limitations on access clear to the user 3) Can we provide the machine with computational alternatives for things to which the user has access.

Given this quick summary of the points which Suchman makes, what can we draw from this work for our educational interaction mechanisms? Her issues about the inadequacy of complete, pre-specified plans are clearly correct, but not of great interest, since AI planning work has never (to my knowledge) made any claims that planning in the real world is anything like that. We accept that people produce partial plans, plans which specify concrete actions or exist in an abstract, partially instantiated form. Recent work on joint planning and execution, and meta-planning leads to a more flexible view of the planning process, into which Suchman's requirements can be incorporated.

Perhaps the most important outcome of this work is the idea of uncertainty of intention, and the vagueness of the idea of context. Both of these, I would claim, point to the way in which planning techniques must be incorporated with the idea of situated actions. The plan, or set of plans (there is no reason to assume an individual is working on a single plan at any given time) provide the context, for a single agent, in which action occurs. This context is necessarily different for each agent, though there are some commonalities. We must not think of a plan, but of an active planning process being carried on through the course of the interaction. The current states of the set of plans are our context, and the "situated actions", which may not be executed as part of a plan, but are necessarily related to plans, contribute not only to plan execution, but to the meta-planning process. This architecture is discussed in more detail in section 6.

5.4 Educational research on interaction

Both the above approaches offer us information about the nature of interaction in general, but they make no proposals specific to the educational interaction. It would seem that the place to look for such information is the educational literature on interaction. This raises the issue of whether AI and education research can derive any benefit from previous work in education. This point is discussed further in [Elsom-Cook 1989], but here we will focus on one aspect of the issue: levels of analysis.

There has been a large amount of work on educational interaction in the classroom, less on small group interaction, and virtually none on one to one educational interaction. Let us set aside this distinction for the moment and assume that it is all relevant to one-to-one interaction with the computer. What can be derived from looking at this literature? Unfortunately, most of this work is descriptive and statistical in nature. It tells us that a teacher spends 40% of her time responding to student initiated activity (or whatever) but offers no help in understanding the processes and mechanisms involved. Similarly, the non-quantitative work, based on sociological and anthropological approaches are of limited value for the types of models and theories which we wish to construct in AI and Education. The analysis is at the wrong level of detail for our

purposes. This is not to suggest that Educational Research should be conducted at a level which is directly formalisable in AI terms. If we were to wait for this state of affairs then we would have to stop asking most educational questions for some time to come, since current AI methods can only describe a small number of educational processes and activities. The problem of levels of description is not that Educational Research is conducted at the 'wrong' level, but that the gap between this level and the detailed level needed for AI approaches is too great to bridge.

The questions which are asked and answered by the literature on Educational Research are often meaningless from the perspective of AI. If a study reports on the effectiveness of a variety of teaching styles, then 'teaching style' must be defined in such a way that it can be expressed formally before the results of the study can even be examined to discover their relevance to AI and Education.

An example of a piece of work on interaction in the educational literature does appear to be relevant to AI issues is [Bellack 1966]. It was intended as a statistical, descriptive study of classroom language use, but in the final chapter it provides some "rules of the language game of teaching". While again being essentially descriptive, these rules do at least provide a framework for talking about the educational issues. They raise some detailed questions which can reasonably be explored using an AI methodology. The rules describe classroom behaviour in terms of four types of language move: soliciting, responding, reacting and structuring. The rules tell us, for example, that the teacher reacts (i.e. comments upon a pupil utterance, as opposed to responding to it) far more often than the pupil does. More strikingly, the pupil does not engage in 'rating' the teacher utterances (e.g. "I agree but...") whereas the majority of teacher reactions are ratings of the pupil. This at least gives us a place where we can begin to ask questions from the AI viewpoint. Why was this difference in reacting behaviour found? Is it specific to a particular teaching style? If so, what is it about that style which makes this distribution of reacting appropriate? What effect does the reaction by the teacher have on the cognitive state of the student? Why is it that teachers rarely react negatively, even if the pupil has said something wrong? In such circumstances the teacher normally reacts in a positive way, but with qualification.

The main point I wish to make here is that we must obviously look at education if we are to find out about educationally specific goals. It is not clear, however, whether we can derive the information we need from existing work. There is a large gap to be bridged in terms of levels of description. If that gap cannot be bridged, then it is necessary for AI and Education to include repetitions of previous research at finer levels of detail.

6. Components of a proposed dialogue system

The general model proposed in this section involves considering interaction as a planning process in which multiple plans are being created simultaneously and are, at a given time, at a variety of levels of abstraction and completeness. These plans can predict actions, but can also be used as a context in which to evaluate actions which they did not predict, and the actions themselves can change the planning process. Planning is not regarded as a process to be completed with a resulting end product which is executed. Planning is dynamic and never-ending. The system can invoke actions without ever generating a complete plan.

To make this clearer, consider the following architecture. A dialogue history consists of a set of utterances generated by the two (we will restrict ourselves to two for present) participants in the interaction. A dialogue model is an abstraction over the dialogue history, representing the 'current state' of the dialogue, both in terms of possible subsequent behaviours by both participants, and in terms of (historical) justifications for those behaviours. A model of an agent is an abstraction over the dialogue model together with knowledge about the world and previous states of the agents. An agent in a dialogue has a model of the other agent and of itself. These models are necessarily inexact. It can, however, contain both knowledge and belief. Plans represent the set of possible expansions of the goals, intentions, wants and desires within an agent. A meta-planning process controls the choice of plans to expand upon and may change the category of the plan (e.g. a desire may become a goal if it is believed to be achievable). Actions can occur because they are predicted by a plan (even if the plan is only partially instantiated) or because the system has a belief that the action is appropriate in the context of the set of plans. The meta-planning process is itself affected by the actions each agent performs.

To make this framework more complete, the following sections will discuss these components in more detail.

6.1 Goals, wants and intentions

A first requirement of our interaction mechanism is that it must be flexible enough to reflect the states of the agents involved in the interaction. By this I mean not just the cognitive states, but also the conative and affective states. This must be the fundamental level of the representation upon which all else is built. It is also important that these states are represented symmetrically (as far as possible) for the two agents (we will continue to think about one to one interaction for the present). The teacher must take account of the state of the student in deciding what to do next, but also compare this with the teacher's own state. If conflicts of goal arise between the agents, then the teacher should attempt to resolve

these by reasoning about the two agents and initiating negotiation where appropriate. This can only be done if the agents are effectively represented in the same way. This level of representation is also important from the perspective of justification. Our teacher must always be able to justify its behaviour at a given time. Referring back to our model of education theory, the part amenable to AI study is that which follows from the given goals and values of a particular educational approach and leads to a model explaining what to do in terms of ways to achieve those goals. I would therefore claim that an initial set of attitudes is the base level of our interaction mechanisms for intelligent tutoring. Other beliefs, wants and desires may be generated during the interaction, but they are elaborations of this base set.

It is not being claimed that we have to wait for a complete theory of agenthood before we can build interaction models. We can state that something is a belief or want and then try to understand how to use it. We do not need to be able to explain the fundamental nature and origins of beliefs and desires in order to make use of them. I would suggest that the following components should be incorporated into the system:

- beliefs attitudes about propositions or states
e.g. believes(tutor, believes(student, not(is-list(NIL))))
- wants... states which the tutor (or student) desires to achieve
e.g. wants(tutor, believes(student, is-list(NIL)))
- commitments...an intention to achieve a state, or carry out an action
e.g. committed(tutor, believes(student, is-list(NIL)))
- preferences - the relative ordering of two attitudes or states
e.g. prefers(tutor, believes(student, is-list(NIL)),
believes(student, is-atom(NIL)))

More justification and explanation of these components, as well as a discussion of the way in which they are used, can be found in [Elsom-Cook in press (b)].

6.2 Planning for simultaneous satisfaction of multiple goals

In the previous section we described a set of goals etc. which must be combined to produce behaviour. To date, dialogue work has taken the view that a single goal is used as the root for a plan which determines the dialogue. This is an obvious simplification in a number of ways. For example, suppose we have asked someone a question, and they get an answer wrong. From this we can acquire a goal of correcting their misconception. But do we say "No", "That was a good try, but..." or "Wrong you idiot"? Each of these will satisfy the stated goal, but some will be appropriate in some situations, and some in others. Which is

appropriate is determined by other goals and beliefs of the teacher, such as maintaining the motivation of the pupil. In general, then, we can regard an action as contributing to the achievement of one or more plans, and each plan may lead to satisfaction of one or more goals (if it is completed).

This raises a second issue, about the types of goals. We have effectively assumed that there is a single type of goal - that which is established and can be completed, after which it will cease to exist. Some goals are generated, satisfied and disappear in this way (e.g. buying a watch). Some can be satisfied, but will recur at a later time (e.g. not being hungry). Some goals do not have a well-defined state of 'achievement', but are used as criteria for assessing action (e.g. being rich and famous). Our planning mechanisms must deal with all these goals, and with levels of abstraction of goal varying from highly abstract ideas such as "make the student independent" to very concrete ones such as "say no".

Given this complexity of goal forms, and the idea that many goals may be tied together by a plan, we are no longer able to talk about plans achieving their goals (except in special cases). Instead, we must return to the idea of getting as close as possible to as many of the goals as possible. Obviously this involves "satisficing" all the goals and then attempting to get additional benefits on individual goals. For example, in the above case of reporting on a student's incorrect answer, the goal of responding is a transient goal that must be completed, while the goal of maintaining student motivation is one that (let us say) can be satisfied by not actually decreasing student motivation. In these terms, all three utterances satisfy the goal of responding, but the insulting comment would not satisfy the motivational goal. Either of the other two responses would therefore be acceptable, but the one with positive reinforcement will be preferred because it takes us closer to our motivational goal.

Another issue for the planner implied by the interaction problem, is that the planning must take into account the goals of both agents. Suchman bemoaned the lack of symmetry in human-computer interaction, and it is even more important in the educational setting. An effective educational interaction relies on negotiation between teachers and pupils (often implicitly) in order to satisfy the goals of both. Several researchers have been examining this problem in tutoring systems recently, notably Petrie-Brown [Petrie-Brown in press] and Baker [Baker in press]. Our interaction planner must deal with goals from both agents consistently, and must have principled reasons if it chooses to prefer the goals of one agent to those of another.

Finally, as has been emphasised in the discussions of DOMINIE and IMPART, the planner cannot operate simply by manipulating syntactic rules. It must be able to justify its behaviour, which in turn implies a semantic model of the planning process. This is necessary in any case for principled meta-planning.

6.3 Plan monitoring

One of the most important points from Suchman's work which must be taken into account is the inexactness of the ability to infer the intentions of another agent, and the necessity of repair as a process that allows agents to jointly determine the meaning of utterances to a level adequate to continue the interaction. This necessarily implies that the agents have beliefs about the effects of their actions, and that these beliefs are used in an evaluative manner. In the architecture described here, these effects are predicted from the set of plans being maintained by the system. These predictions may be inexact.

The existence of such predictions, however, also implies the existence of some monitoring component which seeks evidence that the effects have been achieved (or possibly assumes they have, while seeking evidence that they haven't). For this component, we can derive useful information from the literature on real-world planning produced by the AI community working on problems of robotics. This is not the complete answer to the problem, however, since these techniques rely on being able to derive exact knowledge in a given situation. To apply these ideas to interaction, where the changes in the other participant may not be directly visible, it is necessary to combine them with the uncertain modelling and inferencing techniques discussed earlier.

6.4 Opportunism

Many of the criticisms which Suchman offers of AI planning can be answered with the use of opportunistic planning systems such as [Hayes-Roth 1979]. The system described in that paper makes use of a blackboard architecture and a set of planning specialists to facilitate multi-directional planning. Plans can be created (or partially created) both top-down and bottom up. A local behaviour is established in the context of an intended plan and can affect that plan even though the plan itself is not complete. Another important component of the system, from our point of view, is the facility to meta-plan. The planner can establish models of planning and evaluation criteria to be achieved in a particular context, and can support the simultaneous following of multiple plans. To support such opportunistic processes adequately, it is proposed that the following criteria should be applied to the design:

- Actions performed by the tutor are carried out in the context of one or more currently active plans. This does not mean that the plan must be completed in order to perform the action, but that the tutor has either expanded the plan sufficiently to predict that particular action, or *the tutor has a belief that that action will contribute to the achievement of one or more plans.*

- Any action performed by either tutor or student feeds back into all partially instantiated plans via a meta-planning mechanism. This implies an evaluation function for the effect of an action with respect to a particular plan, even if that action is not predicted explicitly by that plan.

- In order for the meta-planning to function with partial plans it is necessary to introduce the concept of work into the planner. There are two forms of work: 'execution work' and 'planning work'. The former refers to an estimated cost of execution for a given plan (and should be calculable even on incomplete plans in a heuristic manner). The latter refers to an estimation of the further effort required to instantiate the plan.

7. Conclusions

In this paper I have attempted to justify the importance of studying interaction in intelligent tutoring systems. I have illustrated the interaction mechanisms of two systems which embody teaching knowledge at some level. By discussing the limitations of these systems I have raised some issues that require basic research. Following this, some areas which can contribute to this research were outlined, and the components of a sophisticated mechanism for handling educational interaction were discussed. This discussion dealt with the architecture in general terms and highlighted the difficult problems involved in developing each of the components.

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